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Food Chemistry 89 (2005) 253–259

Food Chemistry

www.elsevier.com/locate/foodchem

Physicochemical, cooking and textural properties of milled rice from different Indian rice cultivars

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Received 17 June 2003; received in revised form 16 February 2004; accepted 16 February 2004

Abstract

Milled rices from 23 varieties were evaluated for physicochemical, cooking and textural properties. The relationship between different properties was determined using Pearson correlation. Thousand kernel weight, bulk density, length–breadth (L/B) ratio, and amylose content varied between 13.3–19.9 g, 0.77–0.88 g/ml, 2.62–4.55 and 2.3–15.4%, respectively among the various cultivars. Minimum cooking time, water uptake ratio, gruel solid loss, and elongation ratio varied between 13.3–24.0 min, 2.37–4.45, 1.88–8.53% and 1.29–1.74, respectively. Textural properties, such as maximum force, cohesiveness, packability, hardness and chewiness, determined using an Instron Universal Testing Machine varied between 57–266 N, 40–220 N, 10.0–27.0 mm, 20–91 N/mm, and 1505–6969 N mm, respectively. Cooking time showed a negative correlation with amylose content ($r = -0.70$, $p \leqslant 0.01$) and a positive correlation with bulk density of milled rice ($r = 0.333$, $p \leqslant 0.05$). Gruel solid loss showed a significant positive correlation with the amylose content ($r = 0.880$, $p \leqslant 0.01$) and was negatively correlated with cooking time ($r = -0.708$, $p \leqslant 0.01$). The rice cultivars with higher cooking time showed lower gruel solid loss and vice versa. All textural parameters showed a significant correlation with each other and had a positive correlation with amylose and negative correlation with cooking time.

Keywords: Milled rice; Physicochemical; Amylose; Cooking; Texture

1. Introduction

Rice (*Oryza sativa* L.) is one of the leading food crops of the world and is a staple food of over approximately one-half of the world population. Rice production in India has witnessed a spectacular increase in the recent past and is approximately one-third of the total rice production of the world. The paddy rice production of India was 58.99 million tones in 1985–1986, that rose to 88.55 million tones in 1999–2000. The rice produced in different parts of India varies significantly in composition and cooking quality. Genetic and environmental factors are mainly responsible for variation in composition and cooking quality of rice. For example, the variation in amylose content in rice varieties has been described by a single nucleotide polymorphism in an allele of the waxy gene encoding the granule-bound starch synthase (GBSS) enzyme by Ayres et al. (1997). This polymorphism has been observed to be temperature-dependent by Larkin and Park (1999). The higher environment temperature decreased amylose content in endosperm of non-waxy rice (Asaoka, Okuno, & Fuwa, 1985). A relationship between amylose content and sensory or instrumental values of hardness and inverse relation with stickiness of cooked rice was reported earlier (Juliano, Onate, & del Mundo, 1972; Lorenz, Fong, Mossman, & Saunders, 1978; Sowbhagya, Ramesh, & Bhattacharya, 1987). There are few reports in which cooked rice texture has been related to protein content (Juliano, Onate, & del Mundo, 1965; Onate, del Mundo, & Juliano, 1964). Champagne et al. (1999) and Moriraka and Yasumatsu (1972) observed a minor impact of protein on cooked rice texture.

The objective of the study was to compare the physicochemical, cooking and textural properties of milled rice from different cultivars.

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0308-8146/$ - see front matter
doi:10.1016/j.foodchem.2004.02.032

2. Materials and methods

2.1. Materials

Twenty-three paddy cultivars used throughout this study were procured from Punjab Agricultural University, Ludhiana, India, from the 2002 harvest.

2.2. Methods

2.2.1. Dehusking and milling

The paddy samples were dehusked and milled to remove 6% bran as described earlier (Singh, Singh, Kaur, & Bakshi, 2000). Paddy samples were dehusked on a McGill sample sheller (Rapsco, Brookshire, TX, USA). The brown rice samples obtained were polished in a McGill mill No. 2 (Rapsco, Brookshire, TX, USA) to obtain a 6% degree of milling.

2.2.2. Sample preparation

Milled whole rice kernels were separated from broken rice for the evaluation of physicochemical, cooking and textural properties.

2.2.3. Physicochemical properties

2.2.3.1. 1000-Kernel weight. One thousand head rice kernels of milled rice were counted randomly in triplicate and weighed separately. Mean of three replications was reported.

2.2.3.2. Length–breadth ratio (L/B). Length- and breadth-wise arrangement of milled rice was done and their cumulative measurements (in mm) were taken. The value of *L/B* was determined by dividing length by breadth. A mean of 10 replications was reported.

2.2.3.3. Bulk density. Milled rice kernels from different cultivars were poured into a certain known volume from a fixed height and mass of samples occupying the volume was determined. Ratio was calculated as g/ml.

2.2.3.4. Amylose content. Rice kernels were ground to pass through a B.S.S standard sieve No. 72. Amylose content of the powdered samples from different cultivars was determined using the method of Williams, Kuzina, and Hlynka (1970).

2.2.4. Cooking properties

2.2.4.1. Minimum cooking time. Head rice (2 g) samples were taken in a test tube from each variety and cooked in 20 ml distilled water in a boiling water bath. The cooking time was determined by removing a few kernels at different time intervals during cooking and pressing them between two glass plates until no white core was left.

2.2.4.2. Water uptake ratio. Head rice samples (2 g) for each cultivar were cooked in 20 ml distilled water for a minimum cooking time in a boiling water bath. The contents were drained and the superficial water on the cooked rice was sucked by pressing the cooked samples in filter paper sheets. The cooked samples were then weighed accurately and the water uptake ratio was calculated.

2.2.4.3. Elongation ratio. Cumulative length of 10 cooked rice kernels was divided by length of 10 uncooked raw kernels and the result was reported as elongation ratio.

2.2.4.4. Gruel solid loss. Head rice samples (2 g) in 20 ml distilled water, for each cultivar, were cooked for minimum cooking time in a boiling water bath. The gruel were transferred to 50 ml beakers with several washings and made to volume with distilled water. The aliquot having leached solids was evaporated at 110 °C in an oven until completely dry. The solids were weighed and percent gruel solids were reported.

2.2.4.5. Cooked length–breadth ratio. This was determined by dividing the cumulative length of 10 cooked kernels by the breadth of 10 cooked kernels. A mean of 10 replications was reported.

2.2.5. Textural properties

2.2.5.1. Back extrusion test. The textural properties of the cooked rice have been determined using the procedure described earlier (Singh, Sodhi, Kaur, & Saxena, 2003). A stainless steel (SS) cylinder having diameter 40 mm was used to conduct the back extrusion test. Cooked rice samples (50 g) were cooled to 25 °C and were placed inside the test cylinder and pressed with 150 g weight for 30 s before conducting the test. A SS cylinder plunger with flat base, having diameter 38 mm, was used in conjunction with an Instron Universal Testing Machine (Model 4464, Instron, Buckinghamshire, England) for backward extrusion of the cooked rice. The test was carried out with a 500 N load cell at a crosshead speed of 100 mm/min. A force–distance curve was obtained from the test and the following textural parameters were determined:

hardness – average slope of the initial linear portion of the curve (N/mm),

cohesiveness – force required to initiate the shear and extrusion (N),

packability – distance travelled by the plunger before an average linear slope is reached (mm),

maximum force – the maximum force registered during extrusion (N),

chewiness – area under the curve (N mm).

2.2.6. Statistical analysis

The Pearson correlation coefficients for the relationship between different properties were calculated using Minitab Statistical Software version 13 (Minitab Inc., USA).

3. Results and discussion

3.1. Physicochemical properties

The 1000-kernel weight, bulk density, length-breadth (*L*/*B*) ratio, and amylose content of the milled rice obtained from various cultivars differed significantly (Table 1). IR-8 showed the highest 1000-kernel wt (19.9 g), followed by IET-16313 (19.5 g), IET-16310 (19.4 g), and PR-113 (19.4 g). PR-108 had the lowest 1000-kernel wt (13.3g). Among the different cultivars, bulk density of IR-8 and Jaya was observed to be highest (0.88, 0.87 g/ml, respectively), followed by PR-111 (0.85 g/ml), PR-108 (0.84 g/ml) and PR-103 (0.84 g/ml), whereas Basmati-Super and IET-15391 had the lowest bulk density of 0.77 g/ml. *L*/*B* ratio was observed to be highest for IET-16310 and IET-16313 (4.55, 4.43, respectively). IR-8 cultivar showed the lowest *L*/*B* (2.62). Bulk density of milled rice showed negative correlation with the *L*/*B* ratio of milled rice ($r = -0.652$, $p \leqslant 0.01$). Overall the cultivars having larger grain rice showed lower bulk densities. Fan, Siebenmorgen, Gartman, and Gardisser (1998) reported that the medium-grain cultivars showed a higher bulk density for brown and white rice than did the long-grain cultivars. Amylose content of the milled rice from different cultivars was found to range between 2.3% and 15.4%. Jaya showed the lowest amylose content of 2.3%, whereas PR-113 had the highest amylose content of 15.4%. Singh et al. (2003) have reported an amylose content range of 5.5–11.7% for milled rice from different cultivars.

3.2. Cooking properties

The cooking characteristics of various cultivars are shown in Table 2. Cooking time of milled rice from the different cultivars varied from 13 to 24 min. Jaya had the highest cooking time (24 min), followed by cultivar IR-64 (23 min) and IET-16310 (22.5 min). Basmati-386 and Basmati Pusa-I showed the lowest cooking time of 13 min. Cooking times of less than 20 min for rices with low gelatinization temperature and more than 20 min for those with intermediate gelatinization temperature have been reported earlier. The Pearson correlation coefficients for the relationship between different physicochemical, cooking and textural properties of different rice cultivars are shown in Table 4. The cooking time showed a negative correlation with amylose content ($r = -0.7$, $p \leqslant 0.01$) and a positive correlation with bulk density of milled rice, however, at higher *p*-value ($p \leqslant 0.05$). The relationship between bulk density and cooking time indicates that the rice with higher bulk density, i.e., compact structure, showed a slower water

Table 1
Physicochemical properties of rice kernels from different cultivars

Cultivar	Thousand kernel weight (g)	Bulk density (g/ml)	*L*/*B* ratio	Amylose content (%)
PR-113	19.4	0.81	2.81	15.4
IET-16313	19.5	0.8	4.43	11.7
Bas-super	15.7	0.77	4.00	10.2
PR-111	15.8	0.85	3.90	12.8
Bas-370	16.5	0.80	4.17	14.7
Bas-385	16.1	0.78	3.89	11.6
Bas-386	15.4	0.82	3.78	10.8
PR-114	15.5	0.81	2.94	10.3
RYT-2492	15.8	0.82	3.51	7.5
IET-15391	18.0	0.77	4.40	6.8
PR-106	14.0	0.82	3.78	5.5
Govind	16.8	0.82	3.47	5.4
IR-8	19.9	0.88	2.62	6.8
Bas-Pusa	16.0	0.80	4.39	5.0
PR-115	15.7	0.82	3.28	5.0
Sasyasree	17.3	0.81	2.94	4.1
IR-64	17.3	0.83	3.50	3.9
PR-108	13.3	0.84	2.97	6.8
RYT-2610	16.4	0.81	3.18	4.8
PR-116	18.2	0.81	3.13	2.8
PR-103	15.3	0.84	3.47	3.5
IET-16310	19.4	0.77	4.55	4.0
Jaya	18.3	0.87	2.83	2.3

Table 2
Cooking properties of milled rice from different rice cultivars

Cultivar	Cooking time (min)	Water uptake ratio	Gruel solids loss (%)	Cooked *L*/*B* ratio	Elongation ratio
PR-113	14.3	3.62	8.53	3.13	1.50
IET-16313	14.0	3.84	8.23	4.30	1.44
Bas-super	15.0	3.75	7.15	4.30	1.52
PR-111	18.3	3.25	7.57	3.97	1.40
Bas-370	15.0	3.78	7.02	4.33	1.42
Bas-385	14.1	3.28	6.89	4.80	1.74
Bas-386	13.3	3.45	7.23	4.13	1.38
PR-114	15.3	3.25	6.26	3.29	1.29
RYT-2492	16.0	3.03	5.26	2.32	1.38
IET-15391	16.5	3.07	4.57	3.80	1.40
PR-106	17.0	2.94	5.68	3.90	1.30
Govind	17.5	3.90	4.28	3.00	1.36
IR-8	17.5	2.85	3.76	2.88	1.44
Bas-Pusa	13.3	2.66	3.64	4.40	1.45
PR-115	19.5	2.66	4.23	3.73	1.30
Sasyasree	22.0	4.45	4.10	2.75	1.40
IR-64	23.0	2.55	2.69	3.07	1.29
PR-108	19.5	2.70	2.89	2.82	1.39
RYT-2610	18.0	3.98	3.12	3.09	1.36
PR-116	19.0	2.63	4.27	3.21	1.39
PR-103	19.5	3.83	2.95	2.78	1.32
IET-16310	22.5	2.78	3.89	4.73	1.37
Jaya	24.0	2.37	1.88	3.38	1.32

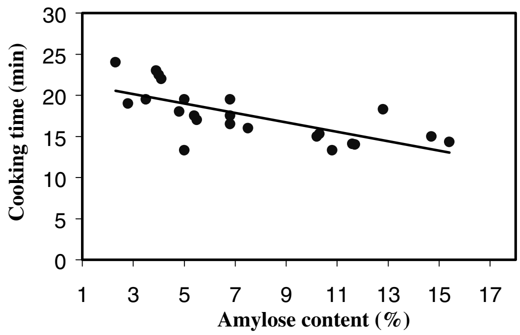

Fig. 1. The relationship between cooking time and amylose content of rice.

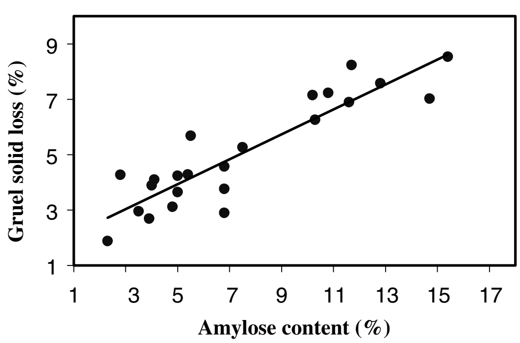

Fig. 2. The relationship between gruel solid loss during cooking and amylose content of rice kernels.

uptake, resulting in longer cooking time. A disorganized cellular structure offers the opportunity for increased water absorption during cooking and, thus, a softer cooked grain (Lisle, Martin, & Fitzgerald, 2000). Fig. 1 illustrates correlation between cooking time and amylose content. The cultivars with higher amylose content required less cooking time. Thus, amylose content and bulk density influence the cooking time, the amylose content having the dominant effect. Water uptake ratio was highest for Sasyasree milled rice whereas IR-64 rice had the lowest water uptake ratio. The gruel solids loss showed highly significant correlation with amylose content ($r = 0.88$, $p \leqslant 0.01$). Fig. 2 shows the relationship between gruel solids loss and amylose content. The gruel solid loss was negatively correlated with bulk density ($r = -0.436$, $p \leqslant 0.05$) and positively correlated with L/B ratio ($r = 0.417$, $p \leqslant 0.05$). The cultivars showing longer working time showed lower gruel solids loss and vice-versa. Gruel solids loss was mainly influenced by the L/B ratio and amylose content. Cultivars with higher L/B ratios offer larger surfaces to contact with water. Amylose is known to leach out during cooking and the higher amylose content is liable to leach more into the cooking water (Juliano et al., 1987; Morris, 1990). Among the rice cultivars studied, Basmati-385 showed the highest elongation ratio (1.74) on cooking, whereas IR-64 and PR-114 rice showed the lowest (1.29). The elongation was observed to be significantly correlated with amylose content. Elongation of cooked rice had positive correlation with L/B ratio as well as the amylose content. Thus, both L/B ratio and amylose content are important in determining the elongation of cooked grains. It has been reported earlier that Basmati type cultivars, such as IET-15391, IET-16310 and IET-16313, having higher L/B ratios, showed greater elongation ratios (1.40, 1.37 and 1.44, respectively). L/B ratio was highest for Basmati-385 cooked grains (4.80) and lowest for PR-103 cooked grains (2.78). L/B ratio of cooked grains showed a positive correlation with amylose content ($r = 0.361$, $p \leqslant 0.05$). Overall, the differences in cooking properties between rice varieties may be due to genetic make up and differences in their amylose contents and granular structures. The long amylopectin chains may crystallize with an amylose molecule, which might extend through adjacent 'clusters', thereby contributing to double helices in several crystallites, which could result in a lower degree of swelling, a reduction in the leaching of solids and harder texture rice (Ong & Blanshard, 1995).

3.3. Textural properties

The textural properties of cooked rice, determined by back extrusion on an Instron machine differed significantly for various cultivars (Table 3). Among the various rice cultivars studied, cooked rice from the cultivar

Table 3
Textural properties of cooked rice from different cultivars

Cultivar	Maximum force (N)	Cohesiveness (N)	Packability (mm)	Hardness (N/mm)	Chewiness (N mm)
PR-113	266	210	25.0	91.0	6969
IET-16313	256	220	26.8	85.6	6953
Bas-super	217	201	26.7	79.6	5950
PR-111	228	184	22.3	73.8	6036
Bas-370	212	196	25.9	68.6	5621
Bas-385	187	169	27.0	67.4	5214
Bas-386	193	177	26.8	60.4	5111
PR-114	126	105	20.5	53.3	3511
RYT-2492	145	107	18.1	48.5	3071
IET-15391	126	101	20.0	46.8	3400
PR-106	119	93	19.6	42.8	3480
Govind	137	103	18.2	42.1	3490
IR-8	109	77	13.7	40.5	2803
Bas-Pusa	105	85	21.3	38.7	3184
PR-115	91	75	18.0	38.1	2881
Sasyasree	108	64	14.8	37.7	2299
IR-64	155	85	15.3	36.8	2637
PR-108	104	81	13.0	35.9	2595
RYT-2610	97	75	13.2	33.0	2593
PR-116	100	63	14.5	30.1	2559
PR-103	78	54	11.6	28.7	1968
IET-16310	57	40	12.2	20.9	1505
Jaya	67	45	10.0	20.0	1637

Table 4
Pearson correlation coefficients for the relationship between physicochemical, cooking and textural properties of milled rice from different rice cultivars

	Thousand kernel wt.	Bulk density	*L/B* ratio	Amylose content	Cooking time	Water uptake	Gruel solid loss	Cooked *L/B* ratio	Elongation	Packability	Maximum force	Cohesiveness	Hardness
Bulk density	−0.31												
L/B ratio	−0.012	−0.652**											
Amylose content	0.001	−0.220	0.207										
Cooking time	0.168	0.333*	−0.155	−0.700**									
Water uptake	−0.034	−0.228	0.286	0.326	−0.248								
Gruel solids loss	0.067	−0.436**	0.417*	0.880**	−0.708**	0.371*							
Cook *L/B*	0.048	−0.565**	0.762**	0.361*	−0.291	−0.064	0.449**						
Elongation	0.148	−0.397	0.226	0.508*	−0.396	−0.051	0.473	0.441*					
Packability	−0.098	−0.379*	0.290	0.832**	−0.831**	0.286	0.866**	0.485**	0.495*				
Maximum force	0.075	−0.261	0.311	0.911**	−0.700**	0.402*	0.916**	0.393*	0.531*	0.859**			
Cohesiveness	0.018	−0.299	0.321	0.923**	−0.733**	0.375*	0.903**	0.454**	0.546*	0.915**	0.981**		
Hardness	0.056	−0.288	0.248	0.924**	−0.729**	0.410*	0.929**	0.345*	0.541*	0.887**	0.978**	0.972**	
Chewiness	0.059	−0.274	0.309	0.912**	−0.717**	0.389*	0.919**	0.431*	0.530*	0.889**	0.994**	0.988**	0.982**

* $p \leqslant 0.05$.
** $p \leqslant 0.01$.

PR-113 showed the highest maximum force (266 N), whereas cooked rice from IET-16310 showed the lowest (57 N). Cohesiveness values were observed to range from 40 to 220 N for cooked rice from different cultivars. Cooked rice kernels from IET-16313 were found to be more cohesive (220 N) than the cooked rice from other cultivars. IET-16310 rice showed the lowest value for cohesiveness (40 N). Basmati-385 cooked rice showed the highest packability, followed by Basmati-386, IET-16313 and Basmati-370. PR-113 also showed a fairly high packability of 25 mm, while a relatively low packability was observed for Jaya, PR-103, PR-108, and RYT-2610 (Table 3). PR-113, IET-16313, Basmati-Super and PR-111 showed higher values for hardness and chewiness, ranging from 73.8 to 91.0 N/mm and 1505 to 6969 N mm, respectively. Basmati-370, Basmati-385 and Basmati-386 showed hardness values from 60.4 to 68.6 N/mm. PR-103, IET-16310 and Jaya had the lowest hardness values (20–28.7 N/mm). All textural parameters had a significant correlation with each other, which showed that these are dependent on each other. All the textural parameters had a very strong positive correlation with amylose content that showed that the amylose content is the most important factor influencing these parameters. The textural parameters showed a negative correlation with cooking time (Figs. 3–6). Figs. 3 and 4

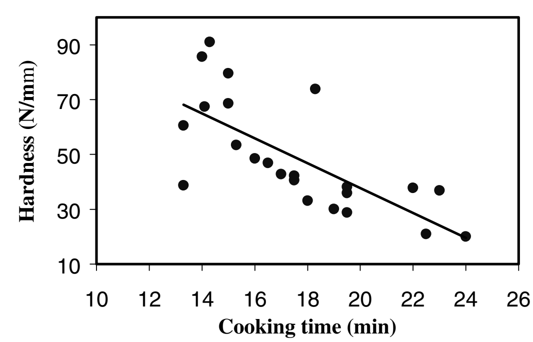

Fig. 3. The relationship between cooking time of rice kernels and hardness of cooked rice.

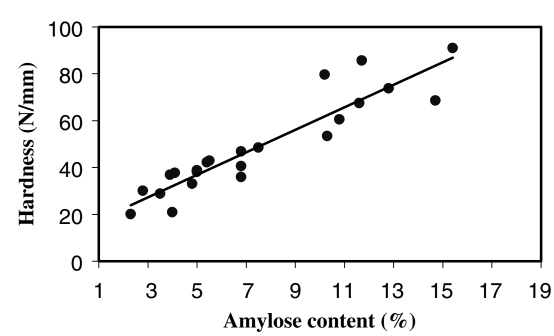

Fig. 4. The relationship between amylose content of rice and hardness of cooked rice.

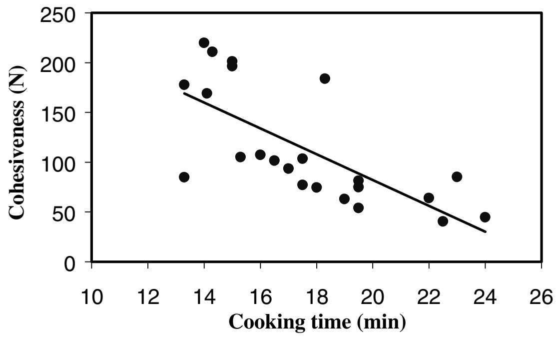

Fig. 5. The relationship between cooking time and cohesiveness of rice.

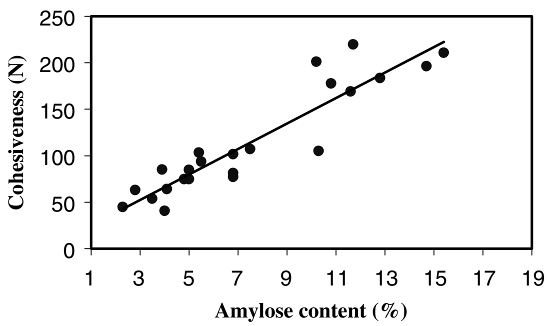

Fig. 6. The relationship between amylose content and cohesiveness of rice.

Fig. 7. The relationship between gruel solid loss during cooking and cohesiveness of cooked rice.

Fig. 8. The relationship between gruel solid loss during cooking and hardness of cooked rice.

illustrate the relationship between hardness value of cooked rice and cooking time and amylose content, respectively. The textural parameters were also observed to be correlated with water uptake, however at higher p value ($p \leqslant 0.05$). The differences in textural properties among the various rice cultivars may be attributed mainly to differences in the amylose content. The higher value of hardness in rice cultivars may also be attributed to differences in their granular structure. A higher hardness has been reported for rice cultivars having smallest size starch granules (Singh et al., 2003). Sowbhagya et al. (1987) observed positive correlation between amylose content and firmness of cooked rice. Ohtsubo, Siscar, Juliano, Iwasaki, and Yakoo (1990) reported a correlation of amylose with texturometer hardness of $r = 0.46$–0.69, for a set of 29 rice samples having amylose in the range of 13.3–16.6%. A range of $r = 0.53$–0.87 for correlations of measurements of Instron hardness with amylose has been observed earlier (Ohtsubo et al., 1990; Perez & Juliano, 1979). Juliano et al. (1987) reported that rice with higher amylose content and long chain amylopectin tended to have a hard texture, while rice with a lower amylose content and short chain amylopectin tended to have a softer texture. The longer amylopectin chains and higher amylose content could provide a favourable milieu for inter- or intra-molecular interactions of starch with other components, such as protein and lipids (Ong & Blanshard, 1995). On the other hand, high concentrations of short amylopectin chains may inhibit this interaction. Kadan, Champagne, Ziegler, and Richard (1997) reported a strong correlation between amylose content of rice and hardness and gumminess after frying. A positive correlation between amylose and sensory value of hardness was reported by Sowbhagya et al. (1987). The texture of a variety of cooked rice was reported to be determined by the content of not only amylose but also the long B chains in amylopectin (Ramesh, Ali, & Bhattacharya, 1999). A significant positive correlation of gruel solid loss was found with cohesiveness ($r = 0.903$) and hardness ($r = 0.929$) (Figs. 7 and 8).

In summary, the physicochemical parameters of rice kernels correlated well with their cooking and textural properties. Amylose content was correlated positively with the solids loss in the gruel and all the textural parameters. The textural parameters showed a significant correlation with each other and had a negative correlation with the cooking time. The cultivars with high amylose content were observed to have a hard texture and less cooking time.

Acknowledgements

The authors are thankful to Dr. P.S. Gill, Director, Regional Rice Research Station, Kapurthala for supply of rice cultivars. The financial support by the Indian

Council of Agricultural Research, New Delhi is acknowledged.

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